Draft
Hunters Point Naval Shipyard
Estimated Excess Cancer Risks and Dose Equivalent Rates from Exposures to Radiological Contamination on Building Surfaces
Report

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1 Introduction

This report describes the calculation of estimated excess cancer risks and dose equivalent rates resulting from potential, future exposures to localized, radiological contamination in impacted buildings at the former Hunters Point Naval Shipyard (HPNS) in San Francisco, California. HPNS was placed on the National Priorities List in 1989 and the Department of the Navy (DON) has been undertaking response actions under its Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) authority in each parcel. These actions are conducted to ensure average, radionuclide-specific radioactivity concentrations on building surfaces do not exceed the remediation goals (RGs) stated in the 2006 Action Memorandum (AM) (NAVFAC, 2006). The RGs presented in Table 1 were intended to be the most conservative available, are applied using the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM, USEPA 2000), and are applied to site- and radionuclide-specific background. For each radionuclide of concern (ROC), the RGs are the lower of the surface concentration limits in Regulatory Guide 1.86 (AEC 1974) or the surface concentration which resulted in 25 millirem (mrem) per year using RESRAD-BUILD, Version 3.3.

Table [SEQ Table * ARABIC \s 1]. Current Building Surface Remediation Goals from 2006 HPNS Action Memorandum

Radionuclide of Concern	Building Surface Remediation Goals (dpm/100 cm^2)
Americium (Am)-241 (^{241}Am)	100
Cesium (Cs)-137 (^{137}Cs)	5,000
Cobalt (Co)-60 (^{60}Co)	5,000
Europium (Eu)-152 (^{152}Eu)	5,000
Eu-154 (^{154}Eu)	5,000
Plutonium (Pu)-239 (^{239}Pu)	100
Radium (Ra)-226 (^{226}Ra)	100
Strontium (Sr)-90 (^{90}Sr)	1,000
Thorium (Th)-232 (^{232}Th)	36.5
Tritium, H-3 (^{3}H)	5,000
Uranium (U)-235+D (^{235}U)	488

In support of the current five-year review, the Navy is evaluating the protectiveness of the current building surface RGs for future occupants, both indoor workers and residents. Under CERCLA, cleanup goals are considered protective if excess cancer risks from site exposures remain within the excess lifetime cancer risk range of 10^{-4} to 10^{-6}. The Navy uses the model RESRAD-BUILD to estimate radiation doses and risks from exposure to surface radiological contamination. Where applicable, the input parameters in RESRAD-BUILD have been adjusted to be consistent with the default parameters used in both the USEPA Building Dose Compliance Concentrations for Radionuclides (BDCC) and Building Preliminary Remediation Goals for Radionuclides (BPRG) online calculators.

RESRAD-BUILD, Version 3.5 ([HYPERLINK "http://resrad.evs.anl.gov/codes/resrd-build/"]) is a downloadable computer code, developed jointly by the Department of Energy and the Nuclear Regulatory Commission. It is considered the industry standard for estimating the dose equivalent and related risk to human health and the environment resulting from exposure to radioactively contaminated building surfaces.

Section 2 provides an overview of the concepts of radioactive decay and the ingrowth of radioactive daughters (progeny) from parent radionuclides. Section 3 describes the use of RESRAD-BUILD, and the

resultant doses and risks, using assumptions about the nature of the radionuclides on HPNS building surfaces and about future occupant exposures to those surfaces.

2 Radionuclide Decay and Progeny Ingrowth

The term radionuclide refers to any nuclide that is unstable and undergoes radioactive decay. Radioactive decay is the spontaneous transformation of the unstable nuclide (parent) into one or more nuclides (daughters or progenies) with an accompanying release of energy or particles. "Radioactivity" or, in short, "activity" (*A*), is the rate of radioactive decay, i.e., the number of nucleus transformations per unit time, and is directly proportional to the number of unstable nuclei in a source[1]. The units of activity are curies (Ci) or becquerels (Bq). One Bq represents one disintegration (decay or transformation) per second (dps), and 1 Ci = 3.7E+10 Bq. One Ci involves a large number of transformations; therefore, a smaller unit, picocurie (pCi), is often used, which is equivalent to 1E-12 Ci. Activity concentration of a radionuclide is defined as the activity (in Ci or Bq) per mass or volume of environmental media (e.g., pCi/gram(g), pCi/liter(L)).

For a given radionuclide, the rate of decay is characterized as the half-life ($T_{1/2}$) and is the average time for half of the initial radionuclide activity (in pCi) to decay. The production of these progenies is referred to as "ingrowth." Progenies can either be stable or radioactive. If the progeny is radioactive, decay will continue until a stable nuclide is reached. A series of sequential radioactive progeny form a decay chain. For the ROCs listed in Table 1:

- The parent radionuclides ^{60}Co, ^{154}Eu and ^{3}H have no radioactive progeny.
- The parent radionuclides ^{137}Cs and ^{90}Sr have one radioactive progeny each.
- The parent radionuclides ^{241}Am, ^{152}Eu, ^{239}Pu, ^{226}Ra, ^{232}Th and ^{235}U form decay chains.

Progeny with half-lives that are short relative to that of their parent will increase in activity until they reach secular equilibrium with the parent. In secular equilibrium, the activity of the progeny equals that of the parent, or some fraction of the parent activity based on the associated branching fraction for that mode of radioactive decay. Within the first 1,000 years of parent ROC decay, the following observations are made from the decay plots in Appendix A:

- ^{241}Am and ^{152}Eu do not reach secular equilibrium with any progeny.
- ^{137m}Ba reaches secular equilibrium nearly immediately with its parent ^{137}Cs. Since ^{137}Cs only decays to ^{137m}Ba 94.4% of the time (the branching fraction for this decay), the maximum ^{137m}Ba activity can only reach 94.4% of the ^{137}Cs activity. The remaining 5.6% of ^{137}Cs decays are to the stable progeny ^{137}Ba.
- ^{90}Sr and its progeny ^{90}Y reach secular equilibrium nearly immediately.
- ^{235m}U is the only progeny to reach secular equilibrium with its parent ^{239}Pu.
- ^{231}Th is the only progeny to reach secular equilibrium with its parent ^{235}U.
- All the progenies reach secular equilibrium with the parent ^{226}Ra according to their branching fractions.
- All progenies reach secular equilibrium with the parent ^{232}Th according to their branching fractions.

[1] Radioactive decay is a statistically random process so this is only true if the number of radioactive atoms in the source is large.

3 Calculation of Dose and Risk Using RESRAD-BUILD

This section summarizes the user-provided inputs and changes to default parameter values (presented in Table 2) needed to calculate the site-specific doses and risks from building surface exposures.

3.1 Dose and Risk Library

Two custom libraries were created using the RESRAD Dose Conversion Factor (DCF) Editor, Version 2.5 (2009) embedded as a tool in RESRAD-BUILD. The custom library called HPNS Adult uses DCFs for external exposures from Federal Guidance Report (FGR) No. 12 (USEPA 1993), DCFs for inhalation and ingestion exposures from International Commission on Radiological Protection Publication 72 (ICRP 1995) for adults, and risk coefficients for total cancer morbidity from the Health Effects Assessment Summary Tables (HEAST) (USEPA 2001). The custom library called HPNS Child uses DCFs for external exposures from FGR 12 (USEPA 1993), DCFs for inhalation and ingestion exposures from ICRP 72 (ICRP 1995) for children (age 15), and risk coefficients for total cancer morbidity from HEAST (USEPA 2001).

3.2 Time Parameters

The estimation of dose and risk in RESRAD is based in part on the amount of time the receptor (indoor worker or resident) is exposed to the source (surface contamination). The total length of time is the product of the exposure duration (days), the indoor fraction and the receptor time fraction. An indoor worker is assumed to be onsite for a work career of 25 years and residents are assumed to reside onsite for 26 years, consisting of six years as a child followed immediately by 20 years as an adult. Adult exposures are assumed to begin at 18 years of age, meaning child exposures occur approximately between 12 and 18 years of age. The time fraction is discussed with Receptor Parameters below.

RESRAD-BUILD integrates doses and risks over the entered exposure duration starting at each evaluation time. For example, with an exposure duration of 365 days, evaluation times at zero, one, two and three years provides the receptor doses and risks for the periods Year 0-1, Year 1-2, Year 2-3 and Year 3-4, respectively.

When dose is a potential Applicable or Relevant and Appropriate Requirement (ARAR), the maximum dose that occurs in any year of exposure is reported as the peak dose in units of mrem/yr. Consistent with Question 35 in USEPA 2014a, if the peak dose is 12 mrem or less, the cleanup goals are considered protective for a residential receptor receiving that dose annually for up to 30 years. For each of the HPNS ROCs, the peak dose occurs where the total activity of the radionuclide, or decay chain, is at a maximum. This occurs in the first year for each ROC as shown in the figures in Appendix A. Thus, the peak dose was determined from the dose at time zero for each ROC, which is the dose accumulated during the first year of exposure to dust on contaminated surfaces, using a 365-day exposure duration.

Cancer risk due to exposure to contaminated surfaces is reported as the lifetime cancer risk accumulated throughout the exposure period. If the summed risks for each year of exposure remain within the 10^{-4} to 10^{-6} range, the cleanup goals are considered protective for the associated receptors. For risk calculations, the exposure durations were increased from the default of 365 days to 9,125 days (25 years) for indoor workers, to 2,190 days (6 years) for child residents and to 7,300 days (20 years) for adult residents to be consistent with the USEPA BPRG Calculator and the USEPA *Update of Standard Default Exposure Factors* (USEPA 2014b).

While the exposure duration drives the length of the period over which doses and risks are integrated, the evaluation times determine the start of each period. For determination of peak dose, the evaluation time is always the default of Year 0 which results in the peak dose during the first year of exposure to

the contaminated surface. Workers are adults during the first year of exposure, while residents are children during the first year. For determination of total worker risk, the exposure period of 9,125 days begins at Year 0 and encompasses the entire 25-year exposure. For total resident risk, the 9,490-day exposure period (26 years) is divided into periods of 2,190 days for child residents and 7,300 days for adult residents. The child resident exposure begins at Year 0, but the adult exposure begins six years later at Year 6.

The default indoor fraction of 0.5 (50%) was changed to 0.68 (250 days each 365 days) for indoor workers and to 0.96 (350 days each 365 days) for both child and adult residents according to USEPA 2014b.

3.3 Building Parameters

Building parameters include the physical size of the room containing the surface contamination, air exchange rate and the rates of contamination deposition and resuspension.

The room floor size was decreased from the default of 36 m^2 to 9.3 m^2, with a room height of 3.05 m, to be consistent with the 10 x 10 x 10 feet room as an option in the USEPA BPRG Calculator and in Finklea 2015. The room is assumed to be 3.05 x 3.05 x 3.05 m.

The building air exchange rate was increased from the default of 0.8 room volume exchanges per hour (1/h) to 1.5 exchanges per hour for nonresidential rooms (i.e., for the indoor worker) according to Table 19-3 in USEPA 2018 and decreased to 0.45 exchanges per hour for residential rooms according to Table 19-1 in USEPA 2018.

3.4 Radiological Units

Source activity was input as disintegrations per minute (dpm) and the output dose measured in milliroentgen equivalent man (mrem). The contamination is modeled as activity per surface area and is entered in the source parameters section in units dpm/m^2.

3.5 Receptor Parameters

Receptor parameters include the fraction of time the worker or resident is in the room with the source, their breathing and ingestion rates, and their location relative to the source.

The time fraction for indoor workers was decreased from the default of 1.0 to 0.33 to reflect an eight hour work day in the room with the source according to the EPA BPRG Calculator and USEPA 2014b. Residents were assumed to spend all their indoor time in the room with the source and the default time fraction was used.

The breathing (inhalation) rate was increased from the default of 18 m^3/day to 60 m^3/day for indoor workers, decreased to 10 m^3/day for child residents and increased to 20 m^3/day for adult residents to be consistent with the USEPA BPRG Calculator, USEPA Standard Default Exposure Factors (USEPA 1991) and USEPA Exposure Factors Handbook (USEPA 1997).

The default ingestion rate of 0.0001 m^2/h was used for adult workers and residents. The ingestion rate for child residents was increased to 0.0002 m^2/h to be consistent with the ratio of child to adult rates in Table 5-1 of USEPA 2017.

The receptor was placed in the center of the 3.05 x 3.05 m concrete floor at location x: 1.5 m, y: 1.5 m, z: 1m, directly above the source.

3.6 Source Parameters

The source type and direction were changed from the default of a volume source radiating in the Y direction to an area source radiating in the Z direction (toward the receptor) consistent with floor surface contamination. The source location was changed from the default of x: 0 m, y: 0 m, z: 0 m to x: 1.5 m, y: 1.5 m, z: 0 m to center the source directly under the receptor location. The source shape was changed from the default of a 36 m^2 disk to a 3.05 x 3.05 m square to cover the entire room floor area.

The removable fraction is the fraction of the source activity that can be removed from the surface from normal cleaning and wear. The default value is 0.5 and the remaining activity is assumed to be fixed activity. The RGs in the 2006 AM for ^{241}Am, ^{137}Cs, ^{60}Co, ^{152}Eu, ^{154}Eu, ^{239}Pu, ^{226}Ra, ^{90}Sr and ^{3}H are based on the surface activity limits in Regulatory Guide 1.86 (AEC 1974) and a removable fraction of 0.2 (20%). The RG in the 2006 AM for ^{232}Th and ^{235}U are based on the source activity that resulted in 25 mrem/yr using RESRAD-BUILD Version 3.3 and a removable fraction of 0.5 (50%). The removable fraction was decreased from the default of 0.5 to 0.2 for all radionuclides to be consistent with the Navy source model assumptions and with radiological survey methodology. All floor surfaces in impacted buildings are surveyed as MARSSIM Class 1 survey units meaning that 100% of the surface areas are prepared for radiological scanning and static measurements. This preparation included cleaning which removes or reduces removable surface contamination. While survey data has historically indicated there is no to little residual activity that is removable, a conservative removable fraction of 0.2 was used in this report.

Lifetime is the time over which the removable fraction is eroded due to activities such as receptor contact and routine cleaning. Since there is no renewal of the source (shipyard operations have ceased using radiological materials), the erosion linearly reduces the source activity over the source lifetime. The lifetime was increased from the default 365 days to the total exposure period for each receptor: 9,125 days for indoor workers and 9,490 days for residents (both as child and adult).

The radon release fraction is the fraction of the total radon produced in either the ^{226}Ra or ^{232}Th decay chains that escapes the contaminated surface to the air. The default of 0.1 (10%) was increased to 0.4 (40%) for the ^{226}Ra chain and decreased to 0.02 (2%) for the ^{232}Th chain to be consistent with the answer to Question 17 in EPA 2014a.

Table 2. Input Values Used to Calculate Peak Doses and Total Risks in RESRAD-BUILD

Input Tab	Parameter	Default Value	Indoor Worker Value	Resident Value	
				Child	Adult
Case	Dose/Risk Library	FGR 11	HPNS Adult	HPNS Child	HPNS Adult
Time Parameters	Exposure Duration (for dose)	365 d	365 d		
	Exposure Duration (for risk)	365 d	9,125 d (25 years)	2,190 d (6 years)	7,300 d (20 years)
	Indoor Fraction	0.5	0.68	0.96	
	Evaluation Times (for dose)	0 yr	0 yr		
	Evaluation Times (for risk)	0 yr	0 yr		6 yr
Building Parameters	Room Area	36 m^2	9.3 m^2		
	Building Exchange Rate	1/hour	1.5/h	0.45/h	
Radiological Units	Activity		dpm		
	Dose		mrem		
Receptor Parameters	Time Fraction	1	0.33	1	
	Breathing Rate	18 m^3/d	60 m^3/d	10 m^3/d	20 m^3/d
	Ingestion Rate	0.0001 m^2/h	0.0001 m^2/h	0.0002 m^2/h	0.0001 m^2/h
	Location	x: 0 m, y: 0 m, z: 0 m	x: 1.5 m, y: 1.5 m, z: 1 m		
Source Parameters	Type/Direction	Volume/Y	Area/Z		
	Location	x: 0 m, y: 0 m, z: 0 m	x: 1.5 m, y: 1.5 m, z: 0 m		
	Removable Fraction	0.5	0.2		
	Lifetime	365 d	9,125 d	9,490 d	
	Radon Release Fraction	0.1	0.4 for ^{222}Rn from ^{226}Ra decay chain 0.02 for ^{220}Rn from ^{232}Th decay chain		
	Radionuclide Concentration	1 dpm/m^2	See Table 3		

3.7 RESRAD-BUILD Input and Output Files

RESRAD-BUILD inputs were modified as described in the previous sections and summarized in Table 2. The following input (*.BLD), and associated output files (*.PDF), were used in the summary of worker and resident potential doses and risks as presented in Section 4. Because RESRAD-BUILD only allows ten sources at a time, the input files were split to run the eleventh ROC, ^{235}U, separately. Note that there is no dose associated with an adult resident because the peak dose occurs in the first year of exposure, while the resident is still considered a child.

Indoor worker dose

- HPNS BUILD IW Am to Pu_25Sep19_9pt3m2_dose.bld
- *HPNS BUILD IW Am to Pu_9pt3m2_25Sep19_FGR 12 ICRP 72 dose.pdf*
- HPNS BUILD IW U_25Sep19_9pt3m2_dose.bld
- *HPNS BUILD IW U_9pt3m2_25Sep19_FGR 12 ICRP 72 dose.pdf*

Indoor worker risk

- HPNS BUILD IW Am to Pu_25Sep19_9pt3m2_risk.bld
- *HPNS BUILD IW Am to Pu_9pt3m2_25Sep19_HEAST risk.pdf*
- HPNS BUILD IW U_25Sep19_9pt3m2_risk.bld
- *HPNS BUILD IW U_9pt3m2_25Sep19_HEAST risk.pdf*

Child resident dose

- HPNS BUILD Child Am to Pu_25Sep19_9pt3m2_dose.bld

- *HPNS BUILD Child Am to Pu_9pt3m2_25Sep19_FGR 12 ICRP 72 dose.pdf*
- HPNS BUILD Child U_25Sep19_9pt3m2_dose.bld
- *HPNS BUILD Child U_9pt3m2_25Sep19_FGR 12 ICRP 72 dose.pdf*

Child resident risk

- HPNS BUILD Child Am to Pu_25Sep19_9pt3m2_risk.bld
- *HPNS BUILD Child Am to Pu_9pt3m2_25Sep19_HEAST risk.pdf*
- HPNS BUILD Child U_25Sep19_9pt3m2_risk.bld
- *HPNS BUILD Child U_9pt3m2_25Sep19_HEAST risk.pdf*

Adult resident risk

- HPNS BUILD Adult Am to Pu_25Sep19_9pt3m2_risk.bld
- *HPNS BUILD Adult Am to Pu_9pt3m2_25Sep19_HEAST risk.pdf*
- HPNS BUILD Adult U_25Sep19_9pt3m2_risk.bld
- *HPNS BUILD Adult U_9pt3m2_25Sep19_HEAST risk.pdf*

Doses are taken from the *Pathway Detail of Doses* section in the Dose Program Output for each source, by pathway, and the external, inhalation and ingestion doses summed to determine the peak dose.

Risks are taken from the *Pathway Detail of Risks* section in the Risk Program Output for each source, by pathway, and the external, inhalation and ingestion risks summed to determine the total risk.

Table 3. Source Input Concentrations, Indoor Worker Doses and Risks, and Resident Doses and Risks from RESRAD-BUILD

Parent ROC	Contributing Progeny	Input Concentration (dpm/m^2)	Peak Dose (mrem/yr)		Total Risk	
			Indoor Worker	Resident	Indoor Worker	Resident
^{241}Am		10,000	0.20	0.48	3.1E-07	1.3E-06
^{60}Co		500,000	1.66	7.12	9.4E-06	4.1E-05
^{137}Cs	^{137m}Ba	500,000	0.42	1.81	5.5E-06	2.4E-05
^{152}Eu		500,000	0.83	3.55	8.3E-06	3.6E-05
^{154}Eu		500,000	0.88	3.77	7.1E-06	3.1E-05
^{3}H		500,000	0.00	0.00	1.4E-10	1.2E-09
^{239}Pu	^{235m}U	10,000	0.19	0.47	3.6E-07	1.6E-06
^{226}Ra	^{222}Rn+D	10,000	0.02	0.22	6.2E-07	3.0E-06
	^{210}Pb+D	10,000				
	^{210}Po+D	10,000				
^{90}Sr	^{90}Y	100,000	0.01	0.03	3.0E-08	2.5E-07
^{232}Th		3,650	0.33	0.75	9.0E-07	3.4E-06
	^{228}Ra+D	3,650				
	^{228}Th+D	3,650				
^{235}U	^{231}Th	48,800	0.28	0.67	7.5E-07	3.3E-06

As shown in Table 3, the resultant RESRAD-BUILD risks for individual radionuclides or radionuclide decay chains are protective for both worker and residential exposures to building surfaces that are uniformly contaminated at the remedial goal levels. While the BPRG calculator includes only ingestion and external exposure pathways for dust on building surfaces, the doses and risks in Table 3 also include the inhalation pathway. Since any building is not uniformly contaminated, the actual risks are expected to be considerably less than these maximum values.

4 Summary

This report describes the use of RESRAD-BUILD to estimate the doses and excess cancer risks to both indoor workers and residents from exposures to HPNS building surfaces uniformly contaminated at the structures remediation goal levels. The assumptions and methods used in this report are very conservative and the use of additional site-specific data and refined exposure scenarios would result in more realistic and lower dose and risk estimates. However, the current estimated risks remain within the 10^{-4} to 10^{-6} range for both exposure scenarios, indicating that remedial goals in the 2006 Action Memorandum are protective for future indoor workers and residents.

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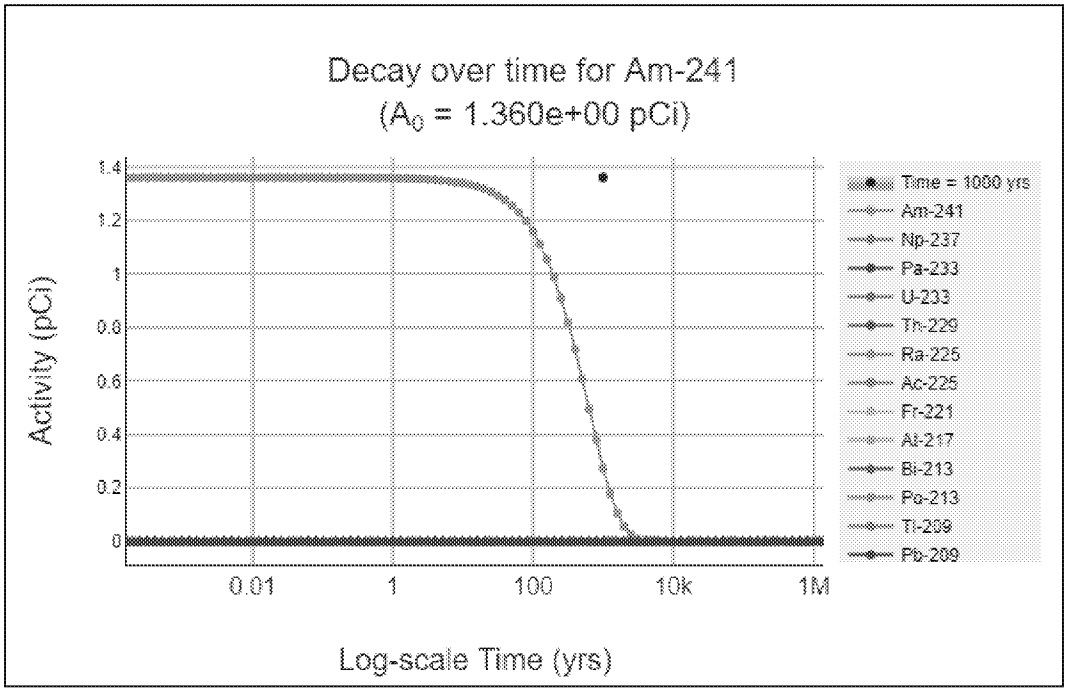
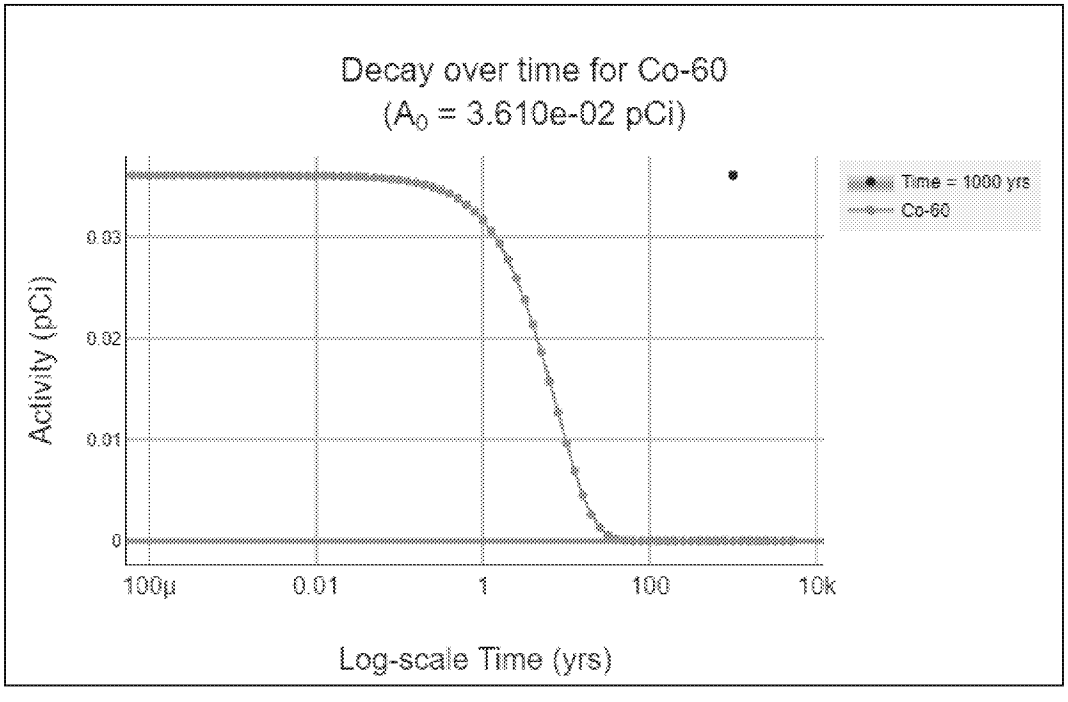
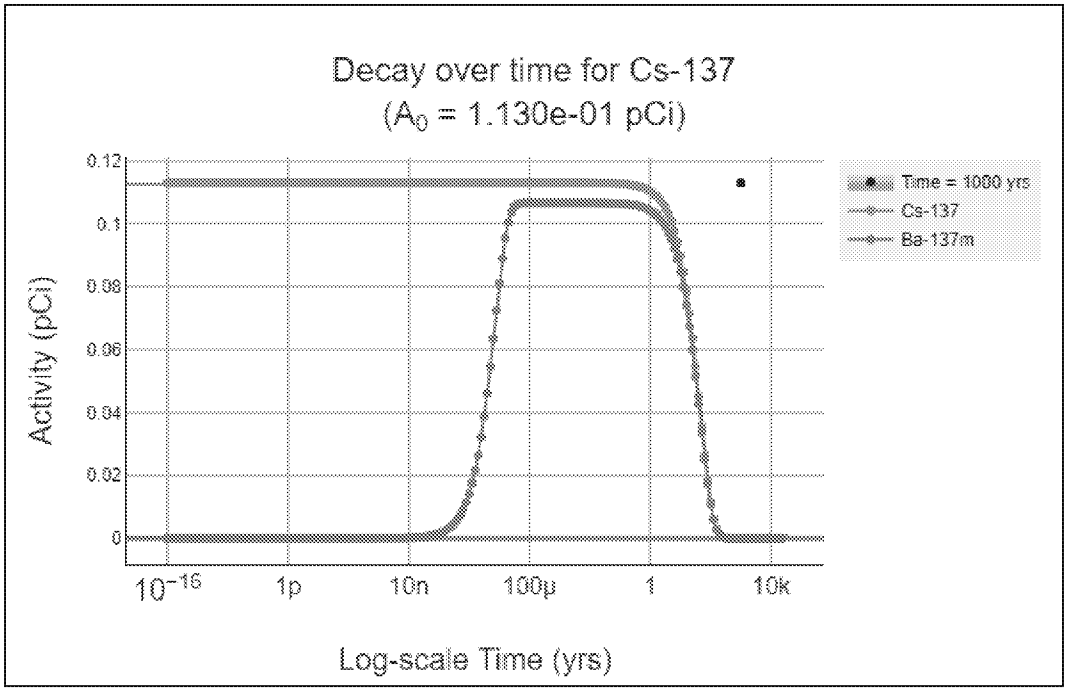
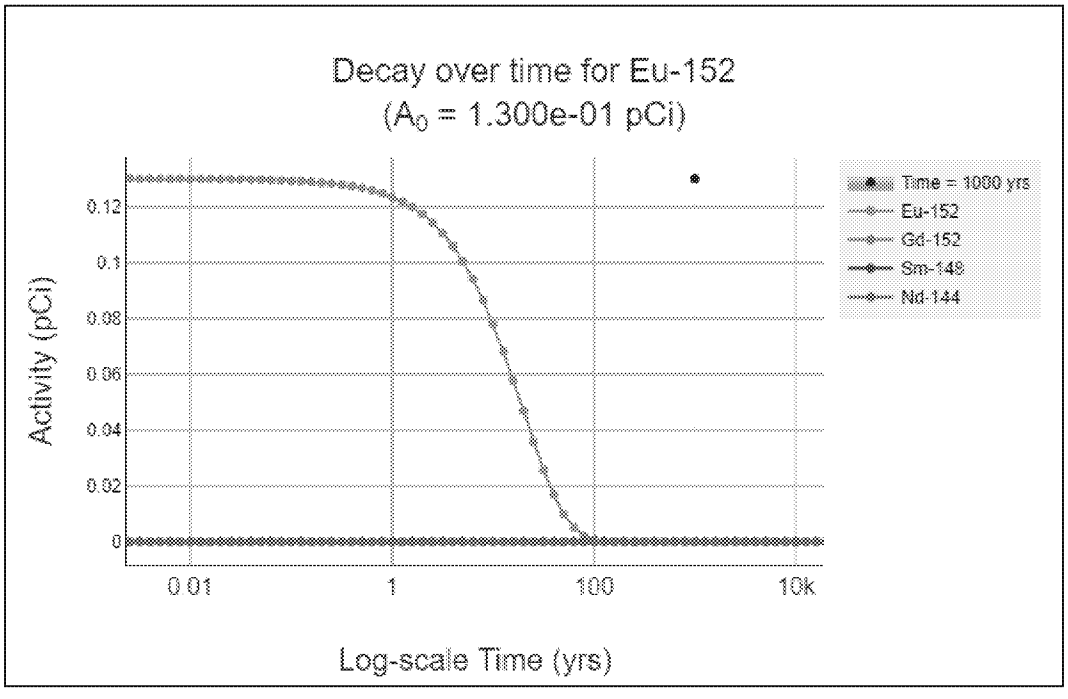
Appendix A. Radioactive Decay Plots

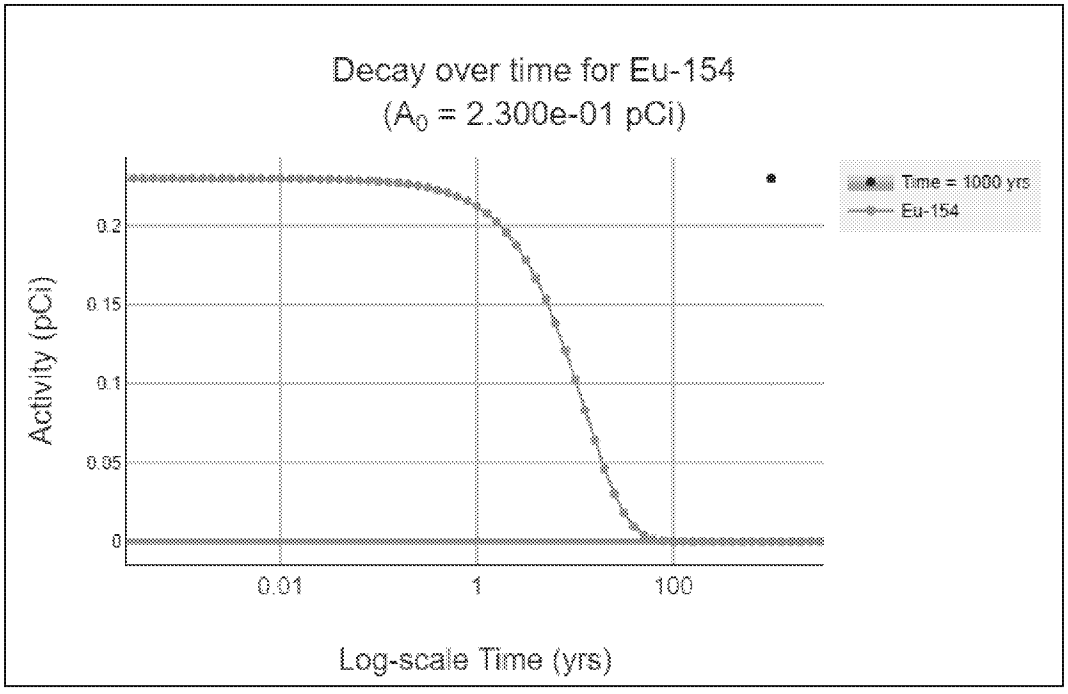
The following plots of radioactive decay for each parent ROC were generated using the Decay Chain Activity Projection Tool ([HYPERLINK "https://rais.ornl.gov/cgi-bin/chain/chain.pl"]) developed by Oak Ridge National Laboratory (ORNL).

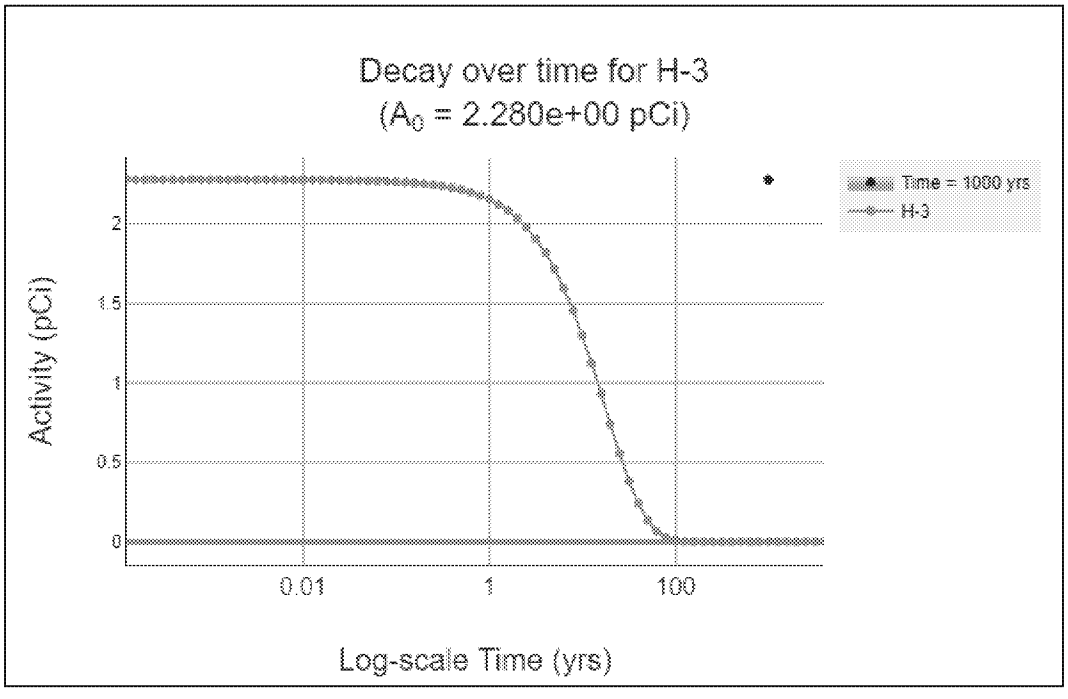


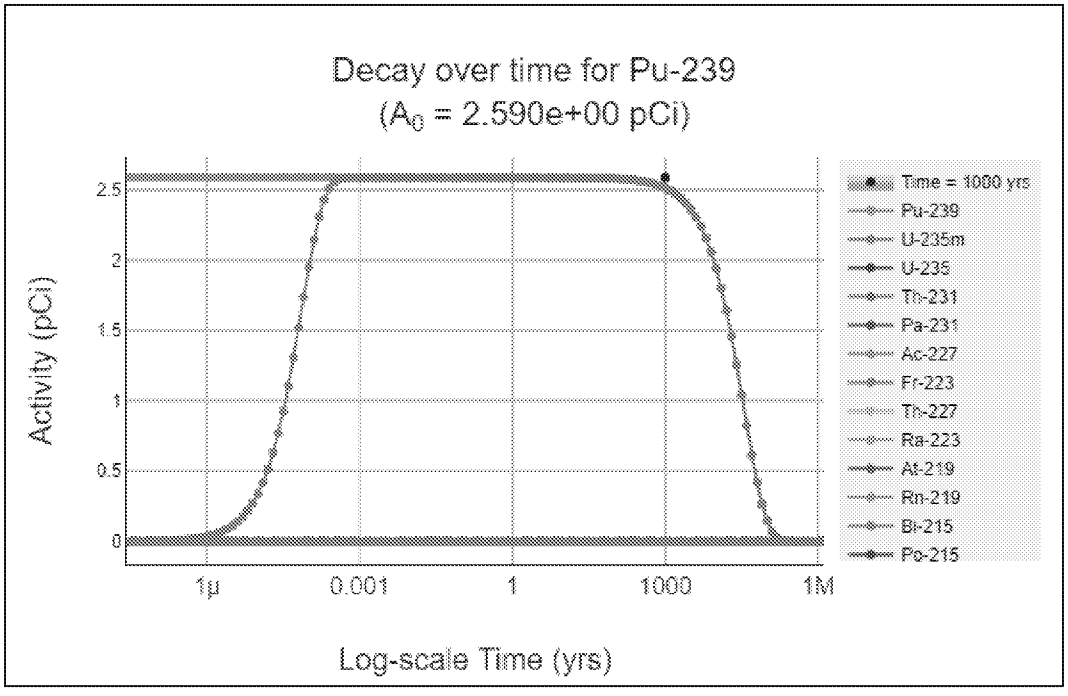


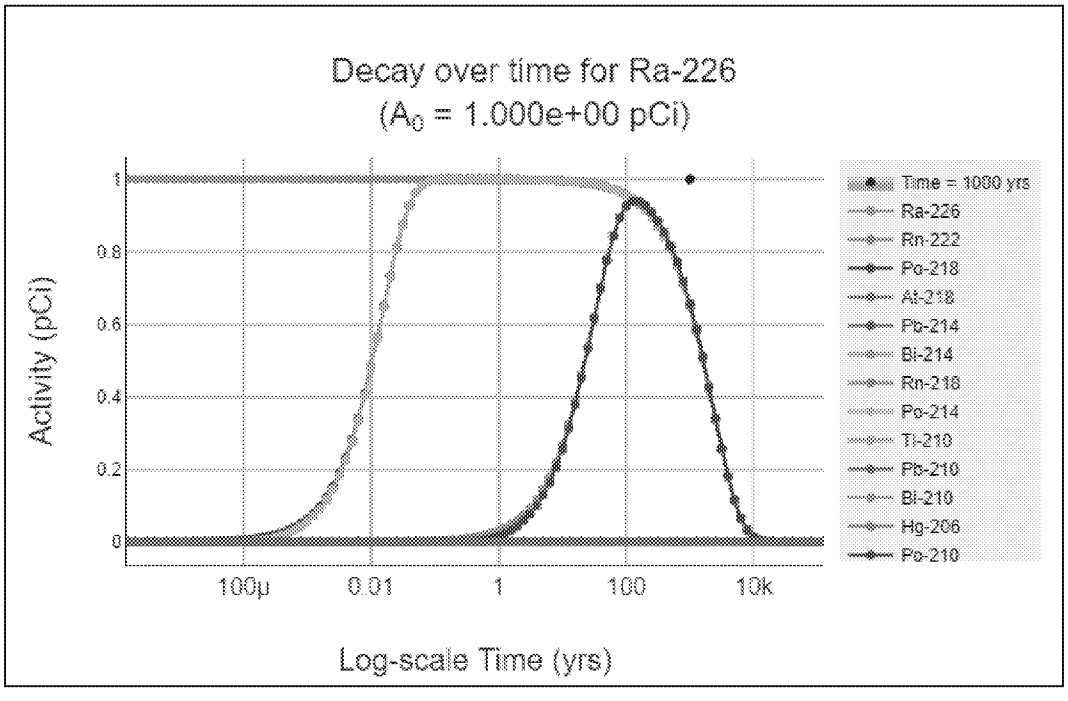

Decay over time for Cs-137
(A_0 = 1.130e-01 pCi)
Activity (pCi)
0.12
0.1
0.08
0.06
0.04
0.02
0
10^{-16}
1p
10n
100µ
1
10k
Log-scale Time (yrs)
Time = 1000 yrs
Cs-137
Ba-137m

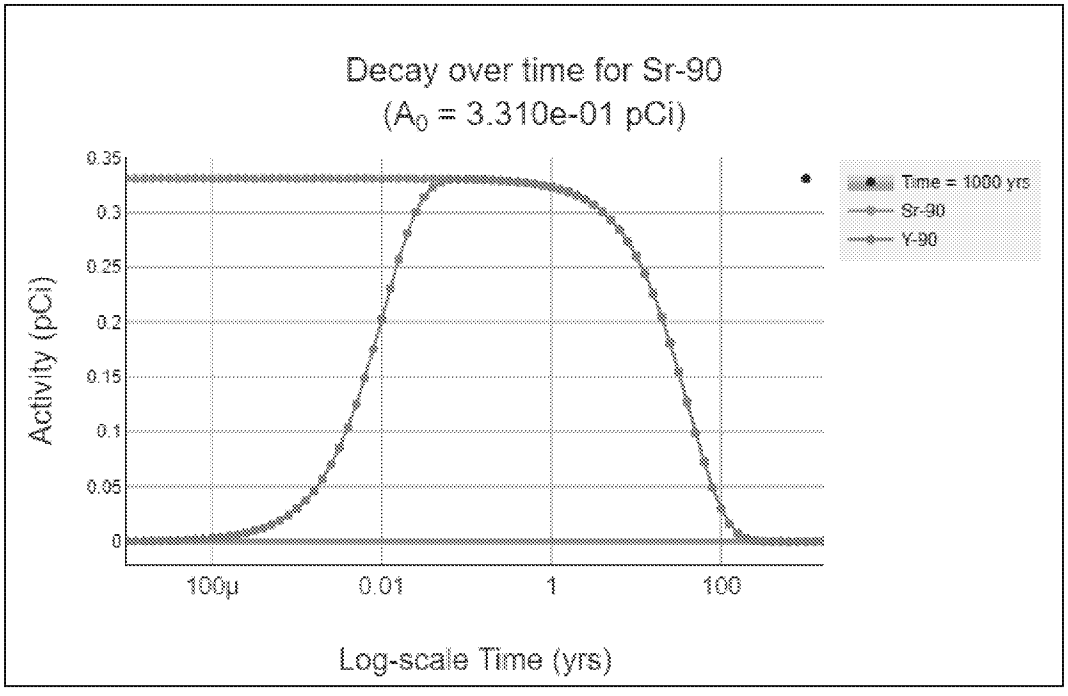

Decay over time for Eu-152
(A_0 = 1.300e-01 pCi)
Activity (pCi)
0.12
0.1
0.08
0.06
0.04
0.02
0
0.01
1
100
10k
Log-scale Time (yrs)
Time = 1000 yrs
Eu-152
Gd-152
Sm-149
Nd-144

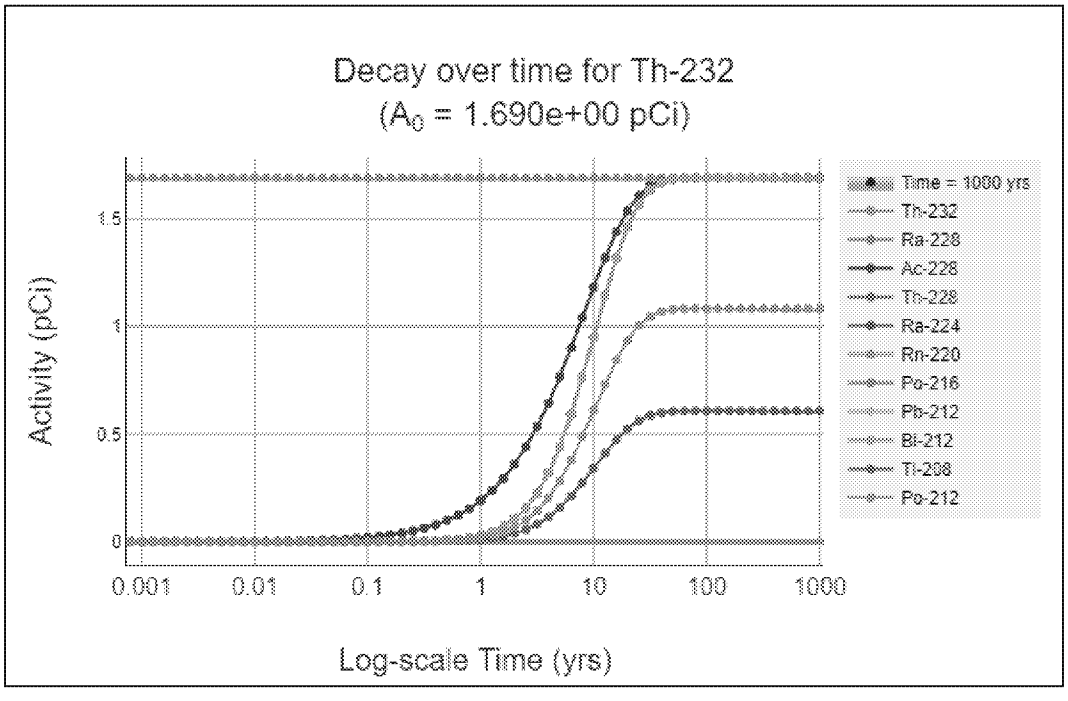

Decay over time for Eu-154
(A0 = 2.300e-01 pCi)
Activity (pCi)
0.2
0.15
0.1
0.05
0
0.01
1
100
Log-scale Time (yrs)
Time = 1000 yrs
Eu-154

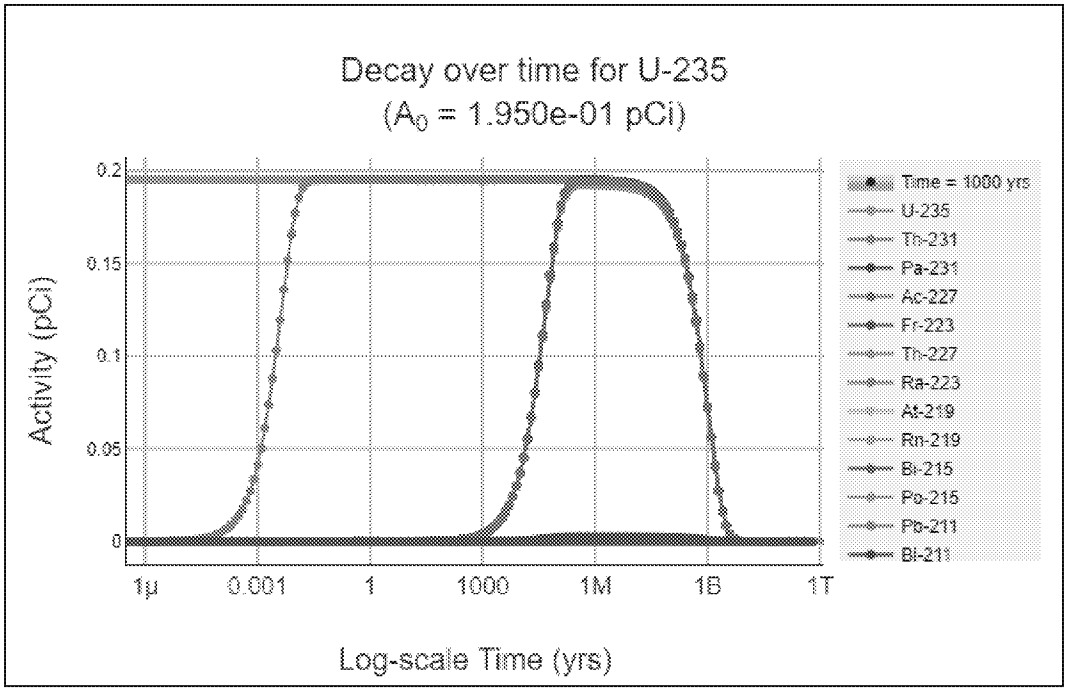

Decay over time for H-3
(A0 = 2.280e+00 pCi)
Activity (pCi)
2
1.5
1
0.5
0
0.01
1
100
Log-scale Time (yrs)
Time = 1000 yrs
H-3


Decay over time for Pu-239
(A_0 = 2.590e+00 pCi)
Activity (pCi)
2.5
2
1.5
1
0.5
0
1µ
0.001
1
1000
1M
Log-scale Time (yrs)
Time = 1000 yrs
Pu-239
U-235m
U-235
Th-231
Pa-231
Ac-227
Fr-223
Th-227
Ra-223
At-219
Rn-219
Bi-215
Po-215


Decay over time for Ra-226
(A_0 = 1.000e+00 pCi)
Activity (pCi)
1
0.8
0.6
0.4
0.2
0
100µ
0.01
1
100
10k
Log-scale Time (yrs)
Time = 1000 yrs
Ra-226
Rn-222
Po-218
At-218
Pb-214
Bi-214
Rn-218
Po-214
Tl-210
Pb-210
Bi-210
Hg-206
Po-210


Decay over time for Sr-90
(A_0 = 3.310e-01 pCi)
Activity (pCi)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
100µ
0.01
1
100
Log-scale Time (yrs)
Time = 1000 yrs
Sr-90
Y-90


Decay over time for Th-232
(A_0 = 1.690e+00 pCi)
Activity (pCi)
1.5
1
0.5
0
0.001
0.01
0.1
1
10
100
1000
Log-scale Time (yrs)
Time = 1000 yrs
Th-232
Ra-228
Ac-228
Th-228
Ra-224
Rn-220
Po-216
Pb-212
Bi-212
Tl-208
Po-212


Decay over time for U-235
(A_0 = 1.950e-01 pCi)
Activity (pCi)
0.2
0.15
0.1
0.05
0
1µ
0.001
1
1000
1M
1B
1T
Log-scale Time (yrs)
Time = 1000 yrs
U-235
Th-231
Pa-231
Ac-227
Fr-223
Th-227
Ra-223
At-219
Rn-219
Bi-215
Po-215
Pb-211
Bi-211

Appendix B. RESRAD-BUILD Input Files

Appendix C. RESRAD-BUILD Output Files